

Differential Response of Rice Germplasm to Straighthead Induced by Arsenic

Wengui Yan,* Robert H. Dilday, Thomas H. Tai, James W. Gibbons, Ronnie W. McNew, and J. Neil Rutger

ABSTRACT

Straighthead disease is a physiological disorder of rice (*Oryza sativa* L.) characterized by sterility of the florets leading to reduced grain yield. Knowledge of the straighthead response of new cultivars is important for producer control of this disease, and identification of resistant germplasm is essential for breeding improved cultivars. The objectives of this study were to characterize U.S. cultivar reactions to straighthead and search for resistant germplasm. Twelve lines, including 10 U.S. cultivars, a Chinese and Japanese cultivar, were tested for straighthead reaction induced by monosodium methanearsonate (MSMA) at 0, 6.7, and 9.0 kg ha⁻¹ under nitrogen fertilizer of 0, 67, 134, and 269 kg N ha⁻¹ in 1999 and 2000. Straighthead delayed heading date, shortened plant height, and dramatically reduced grain yield. Cocodrie, Mars, Kaybonnet, and Bengal were highly susceptible to straighthead with ratings from 7.2 to 8.0 and grain yield reductions from 80 to 96%. Wells, LaGrue, Drew, Cypress, and Japan 92.09.31 were susceptible with ratings from 5.9 to 6.7 and yield reductions from 49 to 73%. Priscilla and Jefferson were tolerant with ratings of 4.9 and 5.3, and yield reductions of 24 and 36%, respectively. The Chinese *indica* cultivar Zhe 733 was essentially immune to straighthead, showing neither symptoms nor detectable yield reduction. A total of 124 Chinese cultivars including 109 *indica* and 15 *japonica* were evaluated for straighthead resistance in 2001. Nineteen cultivars, 18 *indica* and 1 *japonica*, were identified as straighthead resistant. Grain yields of the resistant cultivars were not significantly reduced by their straighthead ratings of 1 to 3. Variation in yield, plant height, maturity, and endosperm type within the resistant germplasm was also observed.

STRAIGHTHEAD is a physiological disorder of rice that results in sterile florets with distorted lemma and palea, and in extreme cases, the panicles or heads do not form at all (Atkins, 1974). As a result, heads remain upright at maturity because of lack of grain development; hence, the name “straighthead.” The diseased panicles may not emerge from the flag leaf sheath when the disease is severe. The lemma and palea, or both, may be lacking, but if they are present, they are distorted and crescent-shaped, particularly in long-grain cultivars, forming a characteristic symptom of straighthead called “parrot beak” (Rasamivelona et al., 1995). Other symptoms include unusually vigorous dark green leaves in mature plants and strikingly abnormal root systems with large, shallow roots with few branches and root hairs (Atkins, 1974; Bollich et al., 1989).

W. Yan and J.N. Rutger, USDA-ARS, Dale Bumpers National Rice Research Center, P.O. Box 1090, Stuttgart, AR 72160; R.H. Dilday, USDA-ARS, Dale Bumpers National Rice Research Center. Present address: 1601 Strait Place, Stuttgart, AR 72160; T.H. Tai, USDA-ARS, CPGRU, Dep. of Agronomy and Range Sciences, Univ. of California, Davis, CA 95616; R.W. McNew, Agriculture Statistics Lab, Univ. of Arkansas, Fayetteville, AR 72701; J.W. Gibbons, Univ. of Arkansas, Stuttgart, AR 72160. Received 9 June 2004. *Corresponding author (wyan@spa.ars.usda.gov).

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677 S. Segoe Rd., Madison, WI 53711 USA

The exact cause of straighthead is unknown, but independent studies have shown that straighthead is increased by consistent flood (Wells and Gilmour, 1977; Wilson et al., 2001), sandy to silt loam textured soils (Collier, 1912; Adair et al., 1973), low soil pH and low free iron (Baba and Harada, 1954), rich organic matter in soil (Jones et al., 1938, p. 28), and high arsenic (As) level in the soil (Wells and Gilmour, 1977; Horton et al., 1983). Straighthead has been frequently observed when rice is grown on land where As has accumulated from previous applications of herbicides with an As base such as monosodium methanearsonate (MSMA) (Gilmour and Wells, 1980).

MSMA is a popular herbicide in cotton (*Gossypium* spp.) production in the USA; therefore, rice fields with a cotton growing history usually have residual As (Gilmour and Wells, 1980). Residual As chemicals in the soil have been shown to cause injuries in rice that are similar to straighthead (Baker et al., 1976; Schweizer, 1967; Wells and Gilmour, 1977; Gilmour and Wells, 1980). Wells and Gilmour (1977) noted that cultivars showing tolerance to MSMA also appeared to be resistant to straighthead. On the basis of this observation, a straighthead testing area based on the application of MSMA has been established at the University of Arkansas, Rice Research and Extension Center near Stuttgart.

Although little is known of the exact causal agent(s) of straighthead, the genetic basis of resistance has been examined in at least three studies. Inheritance of resistance to straighthead in rice has been reported to be dominant in long-grain rice types (Atkins et al., 1957) and recessive in medium-grain types (Xie, 1993) with a single or few genes involved. The heritability of straighthead resistance was reported to be high with minimal interactions between genotype and environment (Rasamivelona et al., 1995). In addition, an interaction between genotype, As, and nitrogen fertility was noticed in straighthead resistance (Dilday et al., 1984). The objectives of the present study were to determine the reactions of major U.S. cultivars to straighthead-inducing levels of MSMA at various nitrogen fertilizer rates and to identify resistant germplasm for incorporation in U.S. rice breeding programs.

MATERIALS AND METHODS

Straighthead Response to Arsenic and Fertilizer

The test was conducted in the straighthead test area on a Crowley silt loam soil (fine, montmorillonitic, thermic Typic Albaqualf) at the University of Arkansas, Rice Research and Extension Center near Stuttgart, AR, in 1999 and 2000. Twelve lines, including 10 cultivars grown in the southern USA, a Chinese cultivar (Zhe 733, PI 629016), and a Japanese germplasm, Japan 92.09.31 (PI 404094) were tested. Eight lines were U.S. long grains (Cocodrie, Cypress, Drew, Jefferson, Kaybonnet, LaGrue, Priscilla, and Wells) and two were U.S. medium grains (Bengal and Mars). The Chinese cultivar and Japanese germplasm line were also medium grains. Drew, Kaybonnet, LaGrue,

Wells, and Mars were cultivars from Arkansas; Cypress, Cocodrie and Bengal from Louisiana; Priscilla from Mississippi; and Jefferson from Texas. Four levels of urea fertilizer (0, 67, 134, and 269 kg ha⁻¹ of nitrogen) and three levels of As (0, 6.7, and 9.0 kg ha⁻¹ of MSMA) were arranged in a split-split plot design, As levels as the main plots, nitrogen rates as subplot, and cultivars as sub-subplots. The plots were replicated four times within each As treatment and served as replication of As. MSMA as a solution was applied to the soil surface and incorporated before planting. Each plot contained nine rows with 0.2-m spacing between rows and rows were 1.5 m long. The tests were planted with a Hege 80 planter on 14 May 1999 and 24 May 2000. Weeds were controlled with 9.3 L ha⁻¹ of propanil (3',4'-dichloropropionanilide) mixed with 0.4 kg ha⁻¹ of quinclorac (3,7-dichloroquinoline-8-carboxylic acid; Facet, BASF) when the rice was about four-leaf stage. The nitrogen fertilizer was applied just before a permanent flood was established at five-leaf stage. The flood was maintained throughout the growing season to ensure ideal straighthead development.

Straighthead was visually rated at maturity in the center of each plot based on floret fertility or sterility and panicle emergence from the flag leaf sheath. The rating scale ranged from 1 to 9, 1 = no apparent sterility (more than 80% grains developed) and about 100% of the panicles emerged; 2 = 71 to 80% of the grains developed and 96 to 100% of the panicles emerged; 3 = 61 to 70% of the grains developed and 91 to 95% of the panicles emerged; 4 = 41 to 60% of the grains developed and 61 to 90% of the panicles emerged; 5 = 21 to 40% of the grains developed and 31 to 60% of the panicles emerged (at this stage distorted and parrot-beak grains initially appear); 6 = 11 to 20% of the grains developed and 10 to 30% of the panicles emerged; 7 = 0 to 10% of the grains developed and most of the panicles emerged but remained totally erect; 8 = no grains developed and 0 to 10% of the panicles emerged from the flag leaf sheath but erect; and 9 = short stunted plants with no panicle emergence.

Heading dates of each plot were recorded when 50% of the panicles emerged from the flag leaf sheath in those treatments in which panicles were visible. At maturity, plant height was measured from the ground to the tip of the panicle. Grain yield was estimated by harvesting 0.9 m of the center three rows in each plot. The data were analyzed by SAS (SAS Inst., 2000).

Identification of Straighthead Resistant Germplasm

One hundred twenty-four accessions of germplasm including 109 *indica* and 15 *japonica* cultivars introduced from China were evaluated for straighthead resistance in 2001. The test entries were separated into four maturity groups from Group 1 (very early maturing) to Group 4 (late maturing) on the basis of previous heading date information and grown in As-treated and -untreated fields. Four cultivars that had been classified for straighthead reaction in the first experiment were included in each group as checks: resistant, Zhe 733; tolerant, Priscilla; and susceptible, Cocodrie and Mars. Arsenic was applied at 6.7 kg ha⁻¹ of MSMA to the soil surface and incorporated before planting. Soil samples were taken before and after the MSMA was applied. The tests were seeded by a Hege 500 planter in the As-treated soil on 19 April, and in a field with clean soil as the check on 20 April 2001 in a split-plot design (maturity groups as main plots, cultivars as subplots) with four replications. Each plot contained six rows with 0.2-m spacing between and rows were 1.4 m long. Weed control and water management were the same as the first experiment. Urea was applied pre-flood at 134 kg N ha⁻¹ at about the five-leaf stage. The flood was maintained throughout the growing season to ensure ideal straighthead conditions.

Straighthead scoring, days to heading and plant height were recorded in the same way as in the previous experiment. The

center two rows in each plot were harvested for grain yield. Lodging was recorded at maturity on a 1-to-9 scale, where 1 had no lodging and 9 had over 80% of plants lodged.

Statistical computing was done by the MIXED procedure of SAS statistical software, Version 8 (SAS Inst., 2000). The dependent variable was yield, the fixed effects in the model were Maturity Group, Cultivar nested within Maturity Group, Treatment as As-treated and untreated, Maturity Group \times Treatment, Cultivar \times Treatment nested within Maturity Group, and the covariable Lodging nested within Maturity Group. The random effects in the model were the residual and the effects of Block nested within the combination of Maturity Group and Treatment. Comparisons of treatments for the same cultivar were *t* tests on the means adjusted to no lodging for excluding lodging from treatment effect, and comparisons among cultivars of the treatment differences were done by multiple *t* tests, each at the 5% significance level.

RESULTS

Effects of MSMA, Nitrogen and Cultivar on Straighthead

Arsenic in the form of MSMA affected straighthead, grain yields, and plant height as shown in Table 1. At 6.7 kg ha⁻¹ of MSMA, the average straighthead rating was 6.2, which was 2.9 greater than at 0.0 kg ha⁻¹ of MSMA, and 0.3 greater than at 9.9 kg ha⁻¹ of MSMA. The rating difference between 0.0 and 6.7 kg ha⁻¹ of MSMA was significant ($LSD_{0.05} = 1.0$), but not between 6.7 and 9.9 kg ha⁻¹ of MSMA. In average, straighthead induced by 6.7 kg ha⁻¹ of MSMA reduced plant height 10 cm or about 11%, delayed heading 4 d, and greatly reduced grain yield. There were no significant differences between MSMA dosages of 6.7 and 9.0 kg ha⁻¹ for these three traits.

Straighthead significantly delayed heading date ($r = 0.39$), shortened plant height ($r = -0.34$), and reduced grain yield ($r = -0.85$). Straighthead rating decreased when nitrogen was increased, but the changes were not large. Conversely, grain yield and plant height increased with the increase of nitrogen. Cultivars showed significantly different straighthead ratings, grain yields, plant heights, and heading dates.

The interaction between As and cultivar significantly affected all the traits tested except heading date. Two-way interactions between As and nitrogen, nitrogen and cultivar, and their three-way interaction were significant only for nitrogen and cultivar on plant height.

In addition, there were small differences among straighthead ratings at 0, 68, 134, and 269 kg ha⁻¹ of nitrogen ap-

Table 1. Variance analysis of straighthead ratings (SH Rating), grain yield (Yield, kg ha⁻¹), plant height (Height, cm) and days to 50% heading (Heading) in rice in response to arsenic, cultivar and nitrogen, replicated in 1999 and 2000.

Source of variation	df	SH Rating	Yield	Height	Heading
<i>F</i>					
Arsenic (As)	2	79.70**	33.41*	6.20*	1.38
Nitrogen (N)	3	4.66*	8.75*	7.96*	6.02*
As \times N	6	0.09	1.71	0.09	0.78
Cultivar (Cult)	11	75.17***	39.23***	78.03***	68.19***
As \times cult	22	4.82***	6.96***	3.49***	0.85
N \times cult	33	0.69	0.72	2.15***	1.11
As \times N \times cult	66	0.35	0.41	0.49	0.41

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

*** Significant at $P < 0.001$.

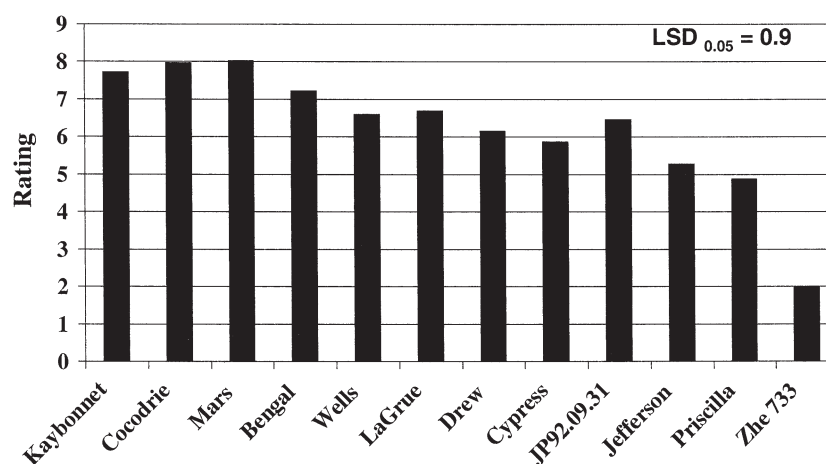


Fig. 1. Straighthead ratings on a 1-to-9 scale, where 1 was normal and 9 was the worst straighthead for rice cultivars tested at 6.7 kg monosodium methanearsonate ha^{-1} and 134 kg nitrogen ha^{-1} in 1999 and 2000.

plied. Also, the difference in ratings between MSMA dosages of 6.7 and 9.0 kg ha^{-1} was small. On the basis of these results, cultivar responses were assessed under MSMA at 6.7 kg ha^{-1} and nitrogen at 134 kg ha^{-1} .

Cultivar Responses to MSMA-Induced Straighthead

Cocodrie, Mars, Kaybonnet, and Bengal were highly susceptible to straighthead with ratings from 7.2 to 8.0 (Fig. 1). Under MSMA treatment, panicles of these cul-

tivars were completely sterile and upright. For example, most grains of Cocodrie became parrot beaked, many panicles failed to emerge, and plants were stubby, resulting in no seed set (Fig. 2). Wells, LaGrue, Drew, Cypress, and Japan 92.09.31 were susceptible to straighthead with ratings from 5.9 to 6.7 (Fig. 1). Most grains on the panicles of these cultivars were sterile, although the plants were not visibly stunted. Priscilla and Jefferson were considered tolerant with straighthead ratings of 4.9 and 5.3,

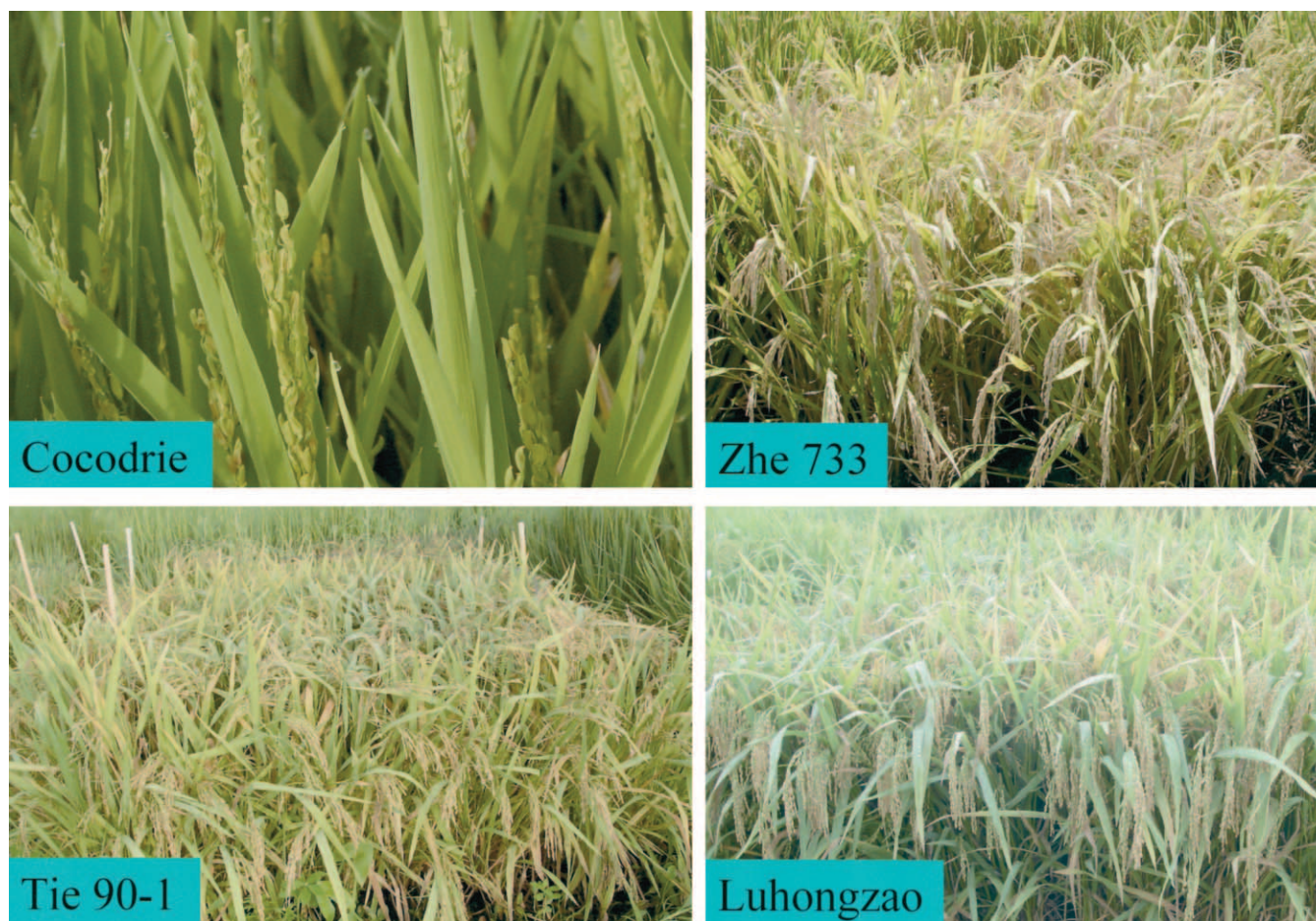


Fig. 2. Mature rice panicles showing higher straighthead reaction in U.S. susceptible cultivar, Cocodrie, compared with three straighthead resistant cultivars from China, identified at 6.7 kg ha^{-1} of monosodium methanearsonate.

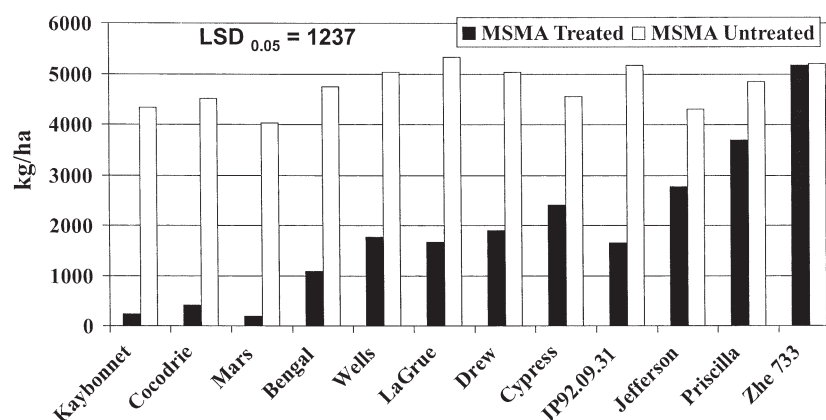


Fig. 3. Grain yield of rice cultivars with no monosodium methanearsonate (MSMA) application (MSMA Untreated) and with 6.7 kg MSMA ha^{-1} (MSMA Treated) fertilized with 134 kg nitrogen ha^{-1} in 1999 and 2000.

respectively. Most of their panicles emerged normally, and about 30 to 50% of the grains were developed as compared with more than 85% developed grains in non-treated plots. Zhe 733, a Chinese *indica* cultivar, was resistant to straighthead with rating of 2.0 in both years. The plant growth and panicle fertility of Zhe 733 were essentially normal (Fig. 2).

Differential Cultivar Yield Reduction Due to MSMA-Induced Straighthead

Over all the cultivars examined, the average grain yield was reduced 60% by straighthead induced at 6.7 kg MSMA ha^{-1} in comparison to non straighthead-inducing conditions (0 kg MSMA ha^{-1}). The highly susceptible cultivars, Cocodrie, Mars, Kaybonnet, and Bengal, exhibited a severe reduction of grain yield, from 80% for Bengal to 96% for Mars as compared with their corresponding untreated MSMA treatment (Fig. 3). The susceptible cultivars, Wells, LaGrue, Drew, Cypress, and Japan 92.09.31, had less severe yield reductions ranging from 49% for Cypress to 73% for LaGrue. The tolerant cultivars, Priscilla and Jefferson, had least yield reductions of 24 and 36%, respectively. Zhe 733, the Chinese *indica* cultivar, had no yield reduction caused by straighthead, indicating that it was immune to soil application of MSMA.

Straighthead Resistant Germplasm

Arsenic content in the treated field was 32.5 kg ha^{-1} before and 40.3 kg ha^{-1} after applying 6.7 kg MSMA ha^{-1} . The untreated check field contained 13.4 kg ha^{-1} of As. Residual As from previous straighthead tests was responsible for the higher level of As in the straighthead test field before applying MSMA than in the untreated check field in 2001. The two highly susceptible checks, Cocodrie and Mars, had very severe straighthead, and their severe reductions of grain yield caused by the straighthead (95–97%) were highly significant (Table 2). The resistant check, Zhe 733, was rated 1 for straighthead and had no yield reduction. These results validated the effectiveness of the test conditions for identifying straighthead resistant germplasm. Lodging occurred in some plots of the As-untreated field, but not in the As-

treated field. Lodging effect on yield reduction caused by straighthead was excluded by covariance analysis for mean comparison of each entry.

Out of the 124 accessions evaluated the nineteen listed in Table 2 showed resistance to straighthead. Among the 19, seven had increases of grain yield from 134 to 1115 kg ha^{-1} under the influence of straighthead, and the other 12 had reductions from 7 to 1197 kg ha^{-1} , but all the increases and decreases were not significant. Their straighthead ratings ranged from 1 to 3 while Cocodrie and Mars were rated 8 and 7, respectively (Fig. 2).

All the resistant cultivars were *indica* except Jing 185-7, which was *japonica*. Nine accessions of the resistant germplasm were in the very early group having 63 to 69 d to heading except Dian No. 01, two in the early group having 83 d to heading, two in the intermediate group having 89 to 90 d to heading, and all six in the late group having 90 or more days to heading except Jing 185-7. Preliminary observation of days to heading had incorrectly classified Dian No. 01 in the very early group. The present results (Table 2) clearly indicate that it belongs in the early group. Plant heights varied from 89 cm for Tie 90-1 in the very early group to 133 cm for Sheng 12 in the late group. Two accessions, Zanu No1 and Jinnuo No6, were waxy endosperm type containing no amylose, and the other 17 nonwaxy accessions had amyloses ranging from 14.8% for Shufeng 121 to 27.0% for Shufeng 109 in their endosperms. Aijiaonante was the first semidwarf cultivar bred in 1956 in China (Qian and Liu, 1993), and Zhenshan 97 was a popular maintainer line of hybrid rice in China (Virmani, 1994).

These straighthead resistant accessions with Plant Introduction (PI) numbers are publicly available in the USDA National Plant Germplasm System at www.ars-grin.gov; verified 16 February 2005.

DISCUSSION

Significance of Straighthead Resistance in Southern U.S. Rice Production

In the early 1900s, Collier (1912) estimated that approximately 20% of the U.S. rice acreage suffered significant yield reductions of 12 to 15% because of straight-

Table 2. Nineteen Chinese rice germplasm accessions had no significant yield reductions from straighthead induced by MSMA (monosodium methanearsonate) at 6.7 kg ha⁻¹ in 2001.

	PI†	Subspecies‡	MSMA untreated§				SH rate¶	MSMA treated#			Yield differences due to SH††	
			Yield	Heading	Height	Lodging‡‡		Yield	Heading	Height	kg ha ⁻¹	P > t
			kg ha ⁻¹	d	cm			kg ha ⁻¹	d	cm		
Very early group 1												
Luhongzao	615199	I	6405	68	92	7	1	7337	70	89	931	0.35
Aijiaonante	614994	I	5826	68	94	4	1	6149	70	90	323	0.72
Zhong 86-44	615202	I	7057	67	97	8	1	7191	69	100	134	0.90
Zhenshan 97	614966	I	6588	69	96	3	1	6467	71	90	-121	0.89
Zao 402	615218	I	6387	68	99	8	1	5929	70	94	-458	0.65
Xiangzaoxian No1	614981	I	9010	68	97	2	1	8550	71	93	-460	0.61
Zanuo No1	614988	I	6927	65	116	5	2	6397	68	110	-523	0.57
Dian No. 01	614991	I	6584	83	128	2	3	5484	87	125	-1100	0.22
Tie 90-1	614999	I	8744	63	89	7	1	7641	66	93	-1102	0.27
LSD 0.05			2375	2	6	3	1	1267	2	8		
CV			27	2	4	48	24	18	2	6		
Early group 2												
Shufeng 109	615014	I	4782	83	121	6	3	5896	88	119	1115	0.27
Danwanbao 24	615214	I	4889	83	99	1	2	5716	84	84	827	0.35
LSD 0.05			1999	2	6	2	1	1428	3			
CV			21	1	4	59	15	43	2			
Intermediate group 3												
Gui 99	614958	I	5954	90	122	1	2	5947	93	104	-7	0.99
Shufeng 117	615017	I	7167	89	127	1	2	6256	93	127	-911	0.31
LSD 0.05			2256	1	5	2	1	1414	2	7		
CV			23	1	3	66	14	44	2	5		
Late group 4												
Jing 185-7	615205	J	6679	88	94	2	3	7072	89	92	393	0.66
Jinnuo No6	614990	I	6383	94	128	3	3	6865	96	117	482	0.59
Sheng 10	615001	I	6935	91	119	1	2	6826	94	110	-108	0.90
Sheng 12	615003	I	6004	91	133	1	3	4901	93	123	-1103	0.22
CDR 22	615008	I	6428	99	113	5	3	5311	102	113	-1117	0.25
Shufeng 121	615015	I	7024	90	122	2	3	5827	93	111	-1197	0.18
LSD 0.05			1514	1	6	2	1	1225	8	10		
CV			16	1	4	57	12	32	6	7		
Zhe 733 (CK)	629016	I	6829	64	99	3	1	6842	67	94	13	0.97
Cocodrie (CK)		J	7409	79	87	1	8	202	89	83	-7207	<0.0001
Priscilla (CK)		J	6350	80	90	1	4	5292	86	86	-1058	0.25
Mars (CK)		J	7006	81	107	1	7	353	88	102	-6653	<0.0001

† PI: Plant Introduction number in the U.S. germplasm system.

‡ Subspecies: I = *indica* and J = *japonica*.

§ No MSMA (monosodium methanearsonate) was applied as check conditions.

¶ Straighthead (SH) rating 1-9: 1 as normal and 9 as the worst SH.

Soil was treated with 6.7 kg MSMA ha⁻¹ to induce straighthead.

†† Yield difference = Treated yield - Untreated yield, and P is probability of t test for the difference.

‡‡ Lodging 1-9 scale: 1 as no plants lodged and 9 as over 80% plants lodged.

head. However, the sporadic nature of straighthead, the lack of a specific causal agent, and the difficulty in finding resistant germplasm has resulted in less emphasis on developing cultivars that address this disorder. Instead, growers employ a practice referred to as “draining and drying,” which appears to attenuate the sterility associated with straighthead (Atkins, 1974; Rasamivelona et al., 1995). In this practice, fields are drained and dried at the 5-leaf stage, about 1 wk after flooding, until cracks appear in the soil and rice leaves begin to curl and exhibit yellowing. The flood is then re-applied for the remainder of the season. For draining and drying to be effective, the soils must be thoroughly dried 10 to 14 d before internode elongation (Wells and Gilmour, 1977).

Although straighthead affects only a small proportion of the Arkansas rice acreage each year, about 20% of the acreage is drained and dried for straighthead prevention (Wilson et al., 2001). Recently, the practice of draining and drying has increased to 35% of rice fields in Arkansas (Wilson, per. Comm.). However, the effectiveness of

draining the flood water and thoroughly drying the soil can be compromised by precipitation. Soil aeration to this extent can also excessively stress the rice plants and complicate other management practices. Producers pay a penalty for this practice because plant stress decreases the full yield potentials of cultivars. Furthermore, draining, drying, and re-flooding the fields increases labor and power usage, which can increase costs to the producers.

In 2001, a total of 1.3 million hectares of rice was grown in the USA with 86% of that total coming from the southern states of Arkansas (49%), Louisiana (17%), Mississippi (8%), Texas (6%), and Missouri (6%) (USDA-ERS, 2002). Widely grown cultivars in the southern USA are very susceptible to straighthead and can show dramatic yield reductions. In the present study, MSMA-induced straighthead resulted in an average yield reduction of 95% for Cocodrie, 49% for Cypress, and 62% for Wells (Fig. 3). The susceptibility of the three cultivars was further confirmed by Wilson et al. (2001). In combination, these three cultivars were grown on 73% of rice hectares

in the southern USA in 2001 (RTWG, 2002). The susceptibility of these widely grown cultivars to straighthead represents a potentially serious threat to southern U.S. rice production.

Growing straighthead resistant and tolerant cultivars is probably the most desirable or cost-effective method of straighthead prevention (Wilson et al., 2001). Resistant cultivars, however, are lacking and currently available tolerant cultivars are limited in the southern U.S. rice production. Priscilla and Jefferson are the only tolerant cultivars available, but they do not yield as well for growers as the three susceptible cultivars, Cocodrie, Cypress, and Wells. For example, the two tolerant cultivars had 2% of rice hectares in the southern states in 2001 (RTWG, 2002). As a result, integrating straighthead resistance into high yielding U.S. cultivars should play an important role in stabilizing rice production and reducing production costs in the southern USA.

Breeding for Straighthead Resistance

We have identified rice germplasm with resistance to straighthead. The resistant germplasms varied in subspecies, plant height, days to heading, and grain endosperm types. These variations among the straighthead resistance cultivars brings great flexibility to breeding. U.S. rices are *japonicas* (Mackill, 1995) and lack straighthead resistance. Zhe 733 and Jing 185-7 represent the straighthead resistant *indica* and *japonica* subspecies, suggesting that resistance is ubiquitous in rice. The present study showed that resistant cultivars were more frequent in *indica* than in *japonica* cultivars. Only one resistant *japonica* cultivar, Jing 185-7, was identified out of 15 *japonica* entries, while 18 of the 109 *indica* entries were resistant.

Zhe 733 matures 2 to 3 wk earlier than typical U.S. cultivars. This raises the question whether straighthead resistance is affected by life cycle length. The reasoning is that a shorter life cycle leaves the plants exposed to the As environment for less time, so that less As is taken up by the plants compared with the late cultivars. Thus the injury from the As is not severe enough to show, which could result in the resistance in Zhe 733. However, the resistant germplasm accessions studied in 2001 had a wide range of maturity with the latest maturing resistant cultivar, CDR 22, heading about 2.5 wk later than the U.S. cultivars. Cocodrie has a very short vegetative stage (shortest of most U.S. cultivars), and its high susceptibility would suggest that resistance is not due to length of time for As uptake. It can be confidently concluded that the resistance is due to genetics, but the inheritance mode needs further study.

The identification of a wide variety of germplasm with resistance to straighthead-inducing levels of MSMA represents the first step in determining the genetic basis of resistance to this disorder and the development of enhanced germplasm that may be incorporated in southern U.S. rice breeding programs.

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